Preliminary observations on a highly-restricted tableland population of Green and Golden Bell frogs on the Upper Molonglo River, NSW.

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ABSTRACT

The Green and Golden Bell Frog *Litoria aurea* disappeared from the Southern Tablelands of New South Wales in the early 1980's and despite many years of opportunistic survey, it was not until 1999 that it was rediscovered near the Upper Molonglo River east of Queanbeyan. The nearest known populations of the species occur at Kioloa, 85 km east of the site. In order to determine the distribution of the population we undertook surveys and monitoring over a two-year period (September 2000 to April 2002) to establish the extent of the population in the region, and to describe the breeding sites that are still occupied. Fieldwork was hampered considerably by extended drought and in some cases by restrictions on access imposed by landholders. All sites surveyed were within 300 m of the Molonglo River. The species was found to occupy 8 of the 10 wetlands (small billabongs) surveyed, 4 of 5 river sites surveyed on the Molonglo River, and at only 1 of 52 farm dams surveyed. It was also heard calling from a small lake on private property. Of the 14 occupied sites surveyed, only three wetland sites supported >10 adult frogs. Additional surveys of the surrounding district, along with a leaflet drop requesting information on any sightings of bell frogs from local landholders, did not reveal any additional populations. Some breeding sites have been affected by cattle grazing and by conversion of native tussock grassland to improved pasture. However, the major threat to this population in the longer term is likely to be the amphibian chytrid fungal pathogen that is present in the population. We speculate that it is possible that the persistence of the species in this area could relate to the historical contamination of the river and floodplain sediments by heavy metals associated with the old mine tailings dam at Captains Flat. It is possible that this pollution has reduced the impact of chytrid on frogs in this region. Management prescriptions, including for livestock activity in and around wetlands, need to be implemented to ensure the ongoing persistence of this important regional population.

Key words: Green and Golden Bell Frog, Molonglo River, frog survey, habitat analysis

Introduction

Green and Golden Bell Frogs *Litoria aurea* were once quite common in the Southern Tablelands of New South Wales (NSW) where they occurred up to about 800 m elevation in the region between Goulburn, Canberra and Braidwood (Osborne *et al.* 1996; Thompson *et al.* 1996). Since the early 1980's the species has undergone an extensive population decline and has disappeared from much of its former range (White and Pyke 1996; Mahony 1999), including from the entire Southern Tablelands (Osborne *et al.* 1996). Recently, a small tableland population of *L. aurea* was discovered on private property on the Upper Molonglo River floodplain to the south east of Queanbeyan, NSW, near Captain's Flat (Wassens and Mullins 2001). The nearest known populations of the species occur at Kioloa, 85 km east of the site (White and Pyke 1996).

The discovery of a population of *L. aurea* near Captain's Flat was unexpected given the apparent extent of the decline that was thought to have occurred in this region (Osborne *et al.* 1996). However, the record is not the first from this particular area - there are specimens held in the Australian National Wildlife Collection, Canberra, that were collected in the 1970's by CSIRO staff at a large lagoon on Foxlow station 6 km from the population discovered by Wassens and Mullins (2001). Although apparently isolated, the upper Molonglo population is not genetically distinct from other NSW populations (Burns *et al.* 2004). Nevertheless, the population is of extreme significance since it is believed to represent the only known surviving population in the Southern Tablelands region (DEC 2005).

Given increasing concern about the conservation of the Green and Golden Bell Frog (DEC 2005), a number of recent studies have attempted to estimate relative abundance and describe the key habitat characteristics for a number of regionally important populations (e.g. Daly1996; Goldingay and Newell 2005a,b). To add to information on the status of these regional populations we conducted surveys to determine the distribution and abundance of *L. aurea* on the upper Molonglo River floodplain and to describe the breeding habitat that appears to influence the occupation of wetlands in this area. The results of surveys conducted between 2000 and 2003 are reported here.

Methods

Study area

The study area was situated approximately 20 km south-east of Queanbeyan, NSW. It included much of the extensive Upper Molonglo River floodplain and adjacent low-lying areas upstream of the Briars Sharrow Road near Hoskinstown, to approximately 10 km north of Captain's Flat (range in elevation 720-760 m AHD). This area included an approximate 20 km stretch of the Molonglo River. The region has a cool, temperate climate, characterised by very cold winters and warm to hot summers. Precipitation in the catchment is relatively evenly distributed throughout the year, and ranges from an average annual precipitation of 590 mm in Queanbeyan to 677 mm at Captain's Flat (Bureau of Meteorology, Canberra). In the area examined the Molonglo River is a small fifth order river draining from an altitude of 1200 m. Due to very low relief, the floodplain is quite extensive and in places is characterised by the presence of secondary stream channels and natural ponds and depressions that are connected to the river during times of high water flow or flooding (Appendix 1). Most of the ponds within the drainage lines dry up during prolonged dry periods (Appendix 1), although some retain water permanently. Large parts of the region have been cultivated and converted to improved pasture, but a feature of much of the immediate floodplain of the Molonglo River is the presence of large areas of perennial tussock grassland dominated by the common tall tussock grass *Poa labillardieri,* and in places, by the exotic pasture species *Phalaris aquatica.* This tussock grassland forms an extensive interconnected matrix that surrounds most of the wetlands.

The area surveyed consisted entirely of private property, and we were allowed access to most (but not all) properties along the river. Several property owners insisted before granting us access to their properties that we agree to ongoing confidentiality with respect to the names and locations of these properties should populations of *L. aurea* be found. In keeping with this agreement the specific locations of some sites are not included in this paper.

Selection of survey sites

All naturally occurring wetlands and constructed ponds (e.g. farm dams) along the river and within the floodplain zone were located by using a combination of aerial photography and topographic map interpretation and advice from farmers. On properties that gave us permission to conduct surveys, we then carried out further on ground searches to locate these and other potential sites for survey. We used our previous experience (e.g. Osborne *et al.* 1996) and descriptions given by Pyke *et al.* (2002) to recognise potential breeding sites. Some sites near roads were included in auditory surveys if frog choruses could be clearly heard from a nearby vantage point within about 30m.

The surveys covered about 70 percent of the total potential area intended for survey. Within this region, 10 wetlands (former stream channel pools) were considered to be large and deep enough to potentially support *L. aurea* populations. These wetlands varied in size - ranging from 55 m to 230 m in length, all less than 20 m wide - and degree of permanency, however, all held water for at least three months (Patmore 2001) and all were within 300 m of the Molonglo River. We were granted permission from property owners to survey approximately 9 km of the Molonglo River though this area. In addition, five sites along the river (no closer to each other than 200 m) were selected as locations for repeated surveys. These sites were considered to provide potential habitat for *L. aurea* because at these locations the river broadened into large, well-vegetated pools with emergent reed beds (mainly *Eleocharis* but also extensive areas of *Restio* and *Phragmites*) that appear to be favoured as basking sites (Pyke *et al.* 2002; Patmore 2001). Sixteen farm dams (artificial stock ponds) occurred on or near the floodplain within 2 km of sites occupied by *L. aurea* (Patmore 2001) and we conducted detailed repeated searches at ten of these. In addition, a further 82 farm dams were located close to public roads in other parts of the study area and were selected for a single auditory survey (see below). Further descriptions of these sites are given in Patmore (2001).

Relative abundance of frogs during repeated surveys

Patmore (2001) found that in this region *L. aurea* were difficult to detect at night (the frogs moved into shelter apparently to avoid cold evening temperatures) so all surveys reported here are based on diurnal visual encounter surveys. These began in early September 2000 and were conducted regularly on an opportunistic basis until April 2002. During most surveys frogs were not captured but were counted by careful visual searches of vegetation and other habitat components within and around wetlands – an earlier trial involving hand-capture of frogs revealed that most frogs that had been caught and toe-clipped later avoided recapture by jumping into the water as the observer approached (Patmore 2001). Individuals seen were recorded as metamorphs if they still had tail buds, and frogs up to approximately 50 mm were recorded as juveniles (Pyke and White 2001).

All river and wetland sites were surveyed at least four times and farm dams used for repeated surveys were surveyed at least twice (Table 1). Searches were conducted by wading slowly through each wetland (where possible) and counting all individuals encountered. Follow-up surveys were also conducted at each site after very wet weather in March 2002. These surveys were conducted over a short period (three days) and were not repeated later in the year. Diurnal surveys were conducted during warm sunny weather and night surveys were conducted between one and four hours after sunset during mild over-cast weather.

Prior to the start of each visual survey, we listened for five minutes to record any individuals of *L. aurea* that were calling. Chorus intensity was recorded as: 0, no frogs heard calling; 1, one frog heard calling; 2, two to six frogs heard calling; 3, more than 6 frogs heard calling. Due to the difficulty of conducting visual surveys in the river, the population size at three of the river sites (R1, R2 and R4) was estimated from calling only.

Road-based auditory surveys of 82 farm dams

Road-based nocturnal audio surveys were used during November and December 2000 to check for calling frogs over a broader region that included all of the low-lying open country between Bungendore, Hoskinstown and Captains Flat (details are given in Patmore 2001). Only one traverse of any given road was made. All public roads that traversed this region were used as survey strips (length traversed totaled 75 km) for audio surveys conducted on suitable evenings when *L. aurea* was calling strongly at two or more monitoring sites. Surveys were conducted at night from a slow-moving vehicle that stopped for five minutes every 500 m for a listening census. In addition listening stops were made adjacent to 82 farm dams, and at flooded ditches and other wetlands that were near the roads. *Litoria aurea* could be heard calling up to 200 m from the road (Patmore 2001), giving an indication of the potential for detecting additional breeding sites in the study area. Audio surveys were only conducted during the first four hours after dusk and were discontinued if the temperature dropped sharply or if conditions became windy or wet.

Habitat measurements

Detailed characteristics of the habitat were measured at the 25 sampling sites at which repeated surveys were undertaken (10 wetlands, 10 farm dams and five river sections). Measurements were made of the length, width and depth of each wetland, pond or river section and a portable field hydrolab (YSI –II, model 610) was used to record pH, conductivity, salinity, temperature, turbidity and dissolved oxygen.

The percentage cover of the dominant aquatic and terrestrial vegetation present at each wetland was estimated by visual inspection. Vegetation was classified as riparian (terrestrial), emergent aquatic, and submerged or floating. The following categories were used for the aquatic vegetation: dominant aquatic vegetation type (DAV); cover of aquatic vegetation (estimated percentage cover of water body) (AVC); cover of submerged and floating vegetation (estimated percentage cover of water body) (S/F V); cover of emergent aquatic vegetation (estimated percentage cover of water body) (EAV); and distance between current water level and the inner edge of the riparian vegetation line (in metres) (DWRVL). The cover of terrestrial vegetation surrounding the wetland was estimated as a percentage (TVC). The composition of the pasture in the surrounding matrix within 20 m of the wetland edge was recorded as: unimproved pasture, consisting of a mix of native and agronomic species (UP); improved pasture, consisting mainly of agronomic species (PI); and tall native tussock grassland *Poa labillardieri* (Poa).

Several landscape scale properties associated with each site were also recorded: the linear distance of each wetland to the nearest site containing *L. aurea* (DTNBS), the distance of sites to the river (DTR) and, the number of sites within a 1km radius supporting *L. aurea* (NSBF<1km).

Habitat analysis

Non-metric multi-dimensional scaling (nMDS, Clarke and Warwick, 1994) was used to determine whether there were any obvious patterns in the sites based on the habitat variables that were measured (water chemistry was not included). This multivariate analysis is essentially a scaling technique, where the rank order of inter-object distances are used to group data (James and McCulloch, 1990).

For the nMDS model, all habitat variables measured (see above) were incorporated into the modelling procedure. The data were log transformed and then used to calculate Bray-Curtis similarity matrices of Euclidean distance. The Bray-Curtis similarity measure was applied to the data because it has a robust monotonic relationship with ecological distance, but it also displays a robust linear relationship until ecological distances become large (Faith *et al.* 1987). When exploring environmental relationships using the nMDS algorithm, the stress level of the ordination is the fundamental measure of how well the groupings (based on similarities) can be represented in two dimensional space and is calculated in terms of scatter (Kruskal and Wish, 1978). Ordinations with stress >0.15 were interpreted with caution (Clarke, 1993). The nMDS procedure was performed using 'PRIMER' (Clarke and Warwick, 1994).

Results

Distribution and relative abundance

Litoria aurea was detected at 14 sites in the study area. Due to agreements with landholders the specific location of these sites are not described here; instead a stylised map is included to provide an indication of the extent of the population (Fig. 1). Eight of 10 wetlands searched repeatedly on foot, four of five river sites searched and one of ten farm dams searched were found to support bell frogs. However, local populations of greater than ten adults (total observed in at least one survey period) were detected at only four sites (Table 1). Recently metamorphosed individuals were observed at five wetlands and one site on the Molonglo River (Table 1). An additional local population representing the southern-most occurrence of the species was heard calling from a large lagoon on Yandyguinula Creek on Foxlow station (detected during a listening stop on a nearby public road).

The species was not detected during repeated diurnal and nocturnal surveys at a further nine farm dams that occurred within two kilometers of a known *L. aurea* population. The species was not heard calling at any of the additional 82 farm dams surveyed in the surrounding Hoskinstown – Captains flat region. The species was found to be restricted in its occurrence to an area of less than about 12 square kilometres associated with the low-lying flood plain zone within 300 m of the Molonglo River.

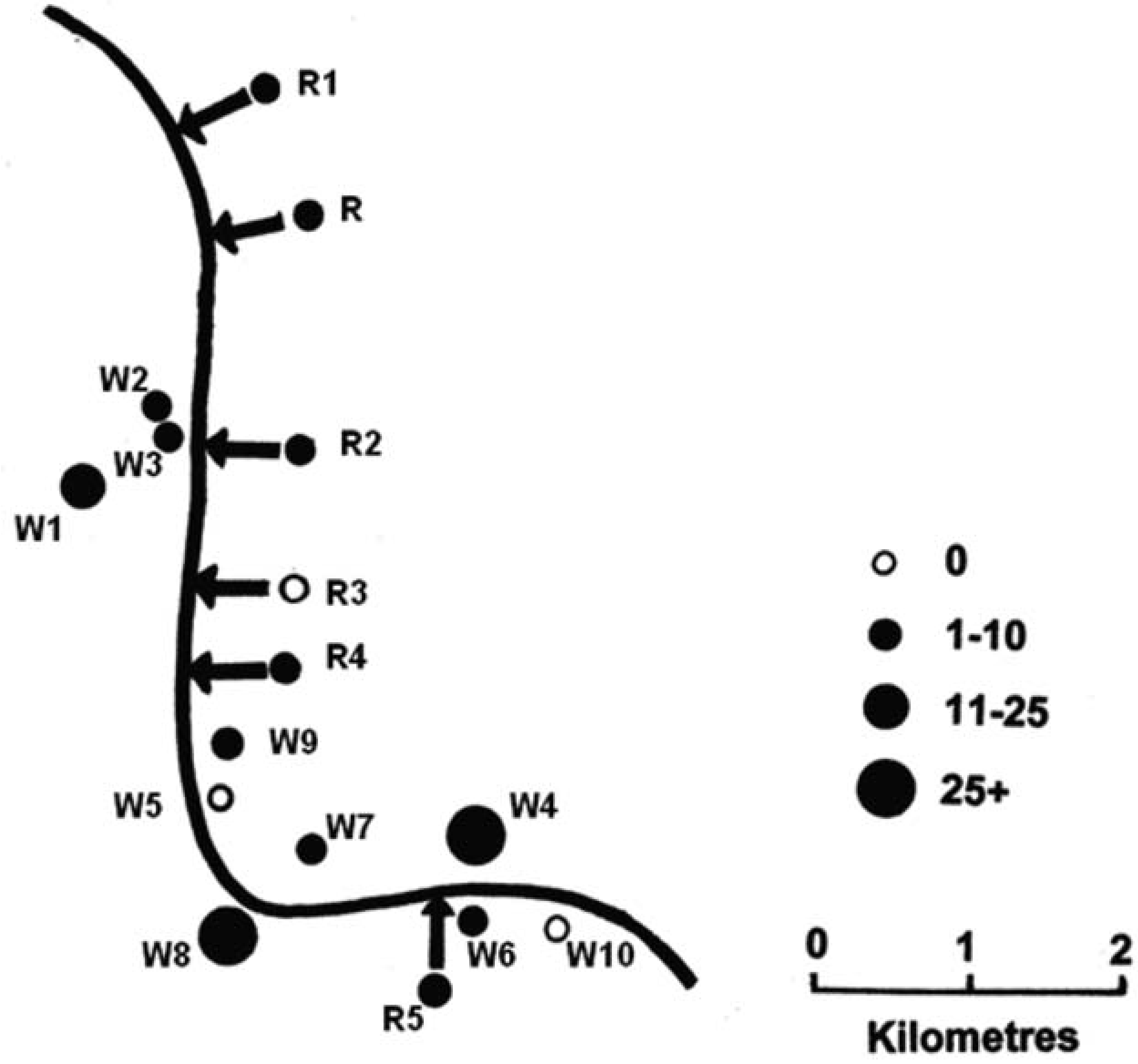

Figure 1. Schematic diagram showing spatial arrangement and site codes for locations surveyed that supported populations of Green and Golden Bell Frogs on part of the upper Molonglo River near Hoskinstown, NSW. W = wetland; R = river; FD = farm dam. Closed circles indicate sites where the frogs were found. The size of the circle indicates the maximum number of individuals counted. Open circles indicate sites that appeared to be suitable but at which the frogs were not detected. Arrows indicate locations surveyed within the river. The figure does not include the Yandyguinula Creek lagoon. The unlabelled river and wetland sites were not used for repeat surveys.

We have not made an estimate of total population size for any site. However, intensive hand-capturing of frogs across eight occupied wetlands during November and December of 2000 resulted in only 115 adults and juveniles being recorded. The maximum number of *L. aurea* (juveniles and adults combined) counted in a single census was in November 2000 when 63 individuals were observed in a wetland (W8).

Seasonal changes in abundance and breeding activity

During 2000-2001 calling was heard at eight sites and loud choruses were heard at four of these locations (Table 1). Calling was first heard on November 14 and continued intermittently until February 12, a period spanning 92 days (Fig. 2). Successful breeding, in the form of production of metamorphs (juvenile frogs recently emerged from the water), occurred at five wetlands and at one river site (Table 1). The first metamorphs were observed in January 2001 and were observed each month through to the last census in May (Fig. 2). Given the emergence of metamorphs in January and the start of calling activity in November, the results are consistent with a November start to breeding.

The repeated sampling in 2000/2001 enabled us to gain some impression of seasonal changes in relative abundance and calling activity at sites that supported more than just a few individuals (wetlands 1, 4 and 8). The first individuals were detected in late September

Table 1. Results of repeated diurnal visual surveys conducted during 2000/2001 for *L. aurea* along the Molonglo River and associated wetlands and farm dams. Surveys were conducted between Sep 2000 and May 2001. Juveniles and adults are combined because of the difficulty of assigning some individuals to either group without capturing them. W = wetland; R = river; FD = farm dam. Wetland area refers to the area of the water body up to the high water mark.

Wetland type and site label	Area (m^2)	Number of repeat surveys	Maximum number of adults and juveniles seen per survey (not including metamorphs)	Maximum number of metamorphs seen	Peak calling intensity
Wetlands					
W1	600	27	23	5	2
W2	683	8	2	0	1
W3	1440	13	15	11	2
W4	4255	21	36	6	3
W5	853	4	0	0	0
W6	1050	4	2	0	0
W7	2320	11	2	0	0
W8	3360	21	63	24	3
W9	1875	12	6	6	0
W10	5720	4	0	0	0
River					
R1	3240	4	2	0	2
R2	4410	6	9	0	3
R3	1440	4	0	0	0
R4	5760	6	6	0	3
R5	640	6	5	2	0
Farm dam					
FD1	1900	3	0	0	0
FD2	1050	6	2	0	0
FD3	300	4	0	0	0
FD4	1225	4	0	0	0
FD5	500	2	0	0	0
FD6	500	2	0	0	0
FD7	400	2	0	0	0
FD8	600	2	0	0	0
FD9	400	2	0	0	0
FD10	1800	3	0	0	0

(23/9) (Fig. 2), and peak activity, defined by the maximum number of individuals observed in a single survey at each site, was observed to be highest in November. At two sites (W1 and W4), the number of frogs detected dropped markedly in mid-summer. At W1 the drop coincided with extensive grazing damage to the aquatic vegetation in the wetland by beetles (the water body became choked with dead vegetation) and at the second site the wetland dried. The number of frogs detected at each site showed a partial increase later in the summer. At a third site with higher number of frogs (W8) there was a consistent decrease in the number of individuals observed from January onward (Fig. 2c). The species was not detected later than May when presumably all frogs had entered hibernation sites.

Characteristics of the habitat at occupied sites

The water bodies at sites associated with wetlands and the river were found to be slightly acidic (pH range: wetlands 6.43 - 7.43; river 6.57 – 6.98; farm dams 7.05 – 8.49) (Table 2). Turbidity was lowest in the river and dissolved oxygen was slightly higher in the river. Salinity was low at all sites (Table 2).

The emergent rush *Eleocharis sphaecelata* and the sedge *Carex appressa* were found to be the most common plant species contributing to wetland cover (both at eight occupied and two unoccupied wetland sites). By contrast there was little vegetation cover at the farm dams surveyed (Table 3). Most wetlands and

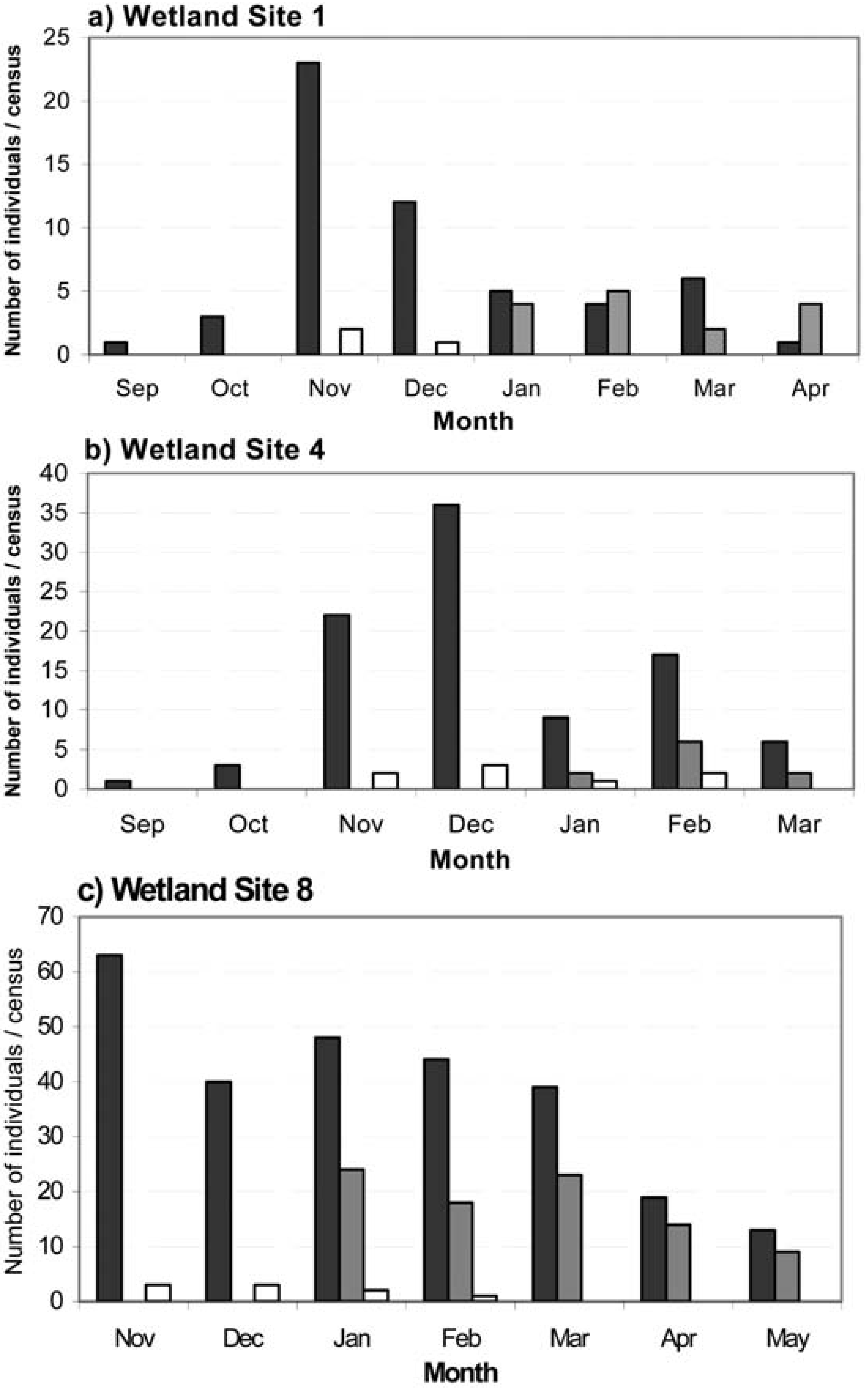

Figure 2. Seasonal changes in the maximum number of frogs (adult and subadult *L. aurea* combined) and metamorphs observed, and peak calling activity on any one day at three wetlands that supported more than ten individuals in 2000-2001. Black bars - number of adult and juvenile frogs observed; Grey bars - number of metamorphs observed; Open bars- peak calling intensity.

Table 2. Chemical properties of sites recorded in February 2001. W = wetland; R = river; FD = farm dam.

Site	Date	PH	Conductivity	Dissolved Oxygen	Dissolved Oxygen	Specific Conductivity	Salinity	Turbidity
			(µS)	(% Sat)	(mg/L)	(µS)		(ntu)
W1	6/02/01	6.98	0.586	16.6	1.49	0.622	0.3	16.2
W2	6/02/01	7.02	0.492	23.2	1.97	0.507	0.24	23.7
W3	7/02/01	6.62	0.238	18.9	1.49	0.227	0.11	35.8
W4	3/02/01	6.52	0.835	22.1	1.48	0.784	0.38	44.6
W5	3/02/01	6.78	0.264	19.2	1.26	0.298	0.18	38.6
W6	7/02/01	7.02	0.323	23.6	1.85	0.343	0.14	26.4
W7	6/02/01	6.39	0.369	25.4	2.17	0.396	0.19	30.3
W8	7/02/01	6.03	0.304	15	1.32	0.332	0.16	18.5
W9	3/02/01	7.43	0.586	40	3.21	0.564	0.27	28.5
W10	3/02/01	7.19	0.604	24.3	2.71	0.636	0.18	41.6
R1	7/02/01	6.84	0.242	22.7	2.22	0.298	0.12	9.8
R2	7/02/01	6.98	0.233	15.3	1.24	0.236	0.11	11.2
R3	16/02/01	6.77	0.255	26.8	2.33	0.273	0.13	6.8
R4	16/02/01	6.71	0.253	31.6	2.75	0.265	0.13	5.1
R5	14/02/01	6.57	0.264	42.6	3.33	0.266	0.13	1.9
FD1	6/02/01	7.05	0.308	14.4	1.19	0.317	0.15	16.9
FD2	6/02/01	8.49	0.361	26.7	2.16	0.373	0.18	41
FD3	6/02/01	7.32	0.191	19.2	1.6	0.202	0.09	64.3
FD4	6/02/01	7.29	0.288	16.3	1.32	0.301	0.17	27.7
FD5	6/02/01	7.11	0.244	18.8	1.41	0.298	0.16	33.9
FD6	6/02/01	7.04	0.265	17.4	1.36	0.288	0.14	41.7
FD7	6/02/01	7.47	0.286	16.2	1.29	0.303	0.09	35.3
FD8	6/02/01	8.01	0.198	18.1	1.38	0.264	0.11	29.6
FD9	3/02/01	7.16	0.212	17.6	0.255	0.287	0.12	31.4
FD10	6/02/01	7.22	0.254	17.9	0.688	0.266	0.14	27.6

sites on the Molonglo River had an extensive cover of aquatic vegetation, and these included the three sites where bell frogs were not found (Table 3). All sites (including farm dams) had at least a 40 percent cover of terrestrial vegetation surrounding them, however, the composition of that cover in terms of dominant species varied across sites from a cover of improved pasture to an almost complete cover of the tall native tussock grass *Poa labillardieri.*

Based on the habitat characteristics, the multivariate analysis (nMDS using the Bray-Curtis similarity measure) defined three groups of sites: river sites (R1-5); wetlands (W1-8) plus four farm dams (FD1,2,4,10); and the remaining six farm dams (Fig. 3). The river sites formed a distinctive group but four farm dam sites were classified into a group that contained all wetland sites. River sites R1, R2 and R4 were large, slow-flowing deep pools whereas Site R3 and R5 were narrower, faster flowing sections of the river. The six farm dams that formed a distinctive group (FD3, FD5, FD6, FD7, FD8 and FD9) lacked aquatic vegetation cover, and none of these sites were found to contain *L. aurea*.

The composition of environmental variables measured appears to be strongly related to the observed pattern of occurrence of *L. aurea* (Fig. 4). Apart from Site 1, which was found to be quite distinctive because of a dense cover of pond milfoil and a lack of an emergent reed bed, the sites with the largest number of *L. aurea* (Sites 3, 4, 8 and 9) showed strong habitat grouping. The most obvious feature in common amongst these sites is that they have a very high cover of aquatic emergent vegetation (Table 1).

Table 3. Characteristics of the dominant vegetation at the sites surveyed repeatedly for *L. aurea* during the 2000/2001 breeding season. Bell frogs were found at the sites marked with an * . AVC: Aquatic Vegetation Cover (estimated percentage cover of water body); S/FV: Submerged and Floating Vegetation (estimated percentage cover of water body); EAV: Emergent Vegetation (estimated percentage cover of water body); DTV: Dominant Terrestrial Vegetation. UP – mixed pasture; IP pasture improved; Poa, *P. labillardieri* tussock); TVC Terrestrial Vegetation Cover (estimated percentage cover within 20m of water body). W = wetland; R = river; FD = farm dam.

Site	Dominant aquatic Vegetation (DAV)	AVC (%)	S/FV (%)	EAV (%)	DTV	TVC (%)	Sites with *L. aurea*
W1	*Myriophyllum sp.*	90	90	10	MP	80	*
W2	*Myriophyllum sp.*	20	90	10	PI	40	*
W3	Aquatic Grasses	70	40	60	Poa	100	*
W4	*Eleocharis sphaecelata*	80	20	80	MP	80	
W5	*Eleocharis sphaecelata*	20	90	10	Poa	80	*
W6	*Carex appressa*	40	40	60	Poa	60	*
W7	*Carex appressa*	40	30	70	Poa	70	*
W8	*Eleocharis sphaecelata*	80	20	80	Poa	80	*
W9	*Eleocharis sphaecelata*	70	10	90	Poa	70	*
W10	Aquatic Grasses	10	100	0	MP	60	
R1	*Nymphaea sp.*	40	80	20	MP	60	*
R2	*Phragmites australis*	40	10	90	MP	70	*
R3	*Phragmites australis*	60	0	100	MP	80	
R4	*Eleocharis sphaecelata*	50	60	40	MP	40	*
R5	*Scirpus validus*	80	0	100	Poa	70	*
FD1	*Nymphaea sp.*	10	100	0	MP	60	
FD2	*Eleocharis acuta*	10	30	70	MP	40	*
FD3	None	0	0	0	PI	10	
FD4	Aquatic Grasses	30	90	10	PI	40	
FD5	None	0	0	0	PI	40	
FD6	None	0	0	0	PI	30	
FD7	None	0	0	0	PI	20	
FD8	None	0	0	0	PI	20	
FD9	None	0	0	0	MP	50	
FD10	*Nymphaea sp.*	10	100	0	MP	60	

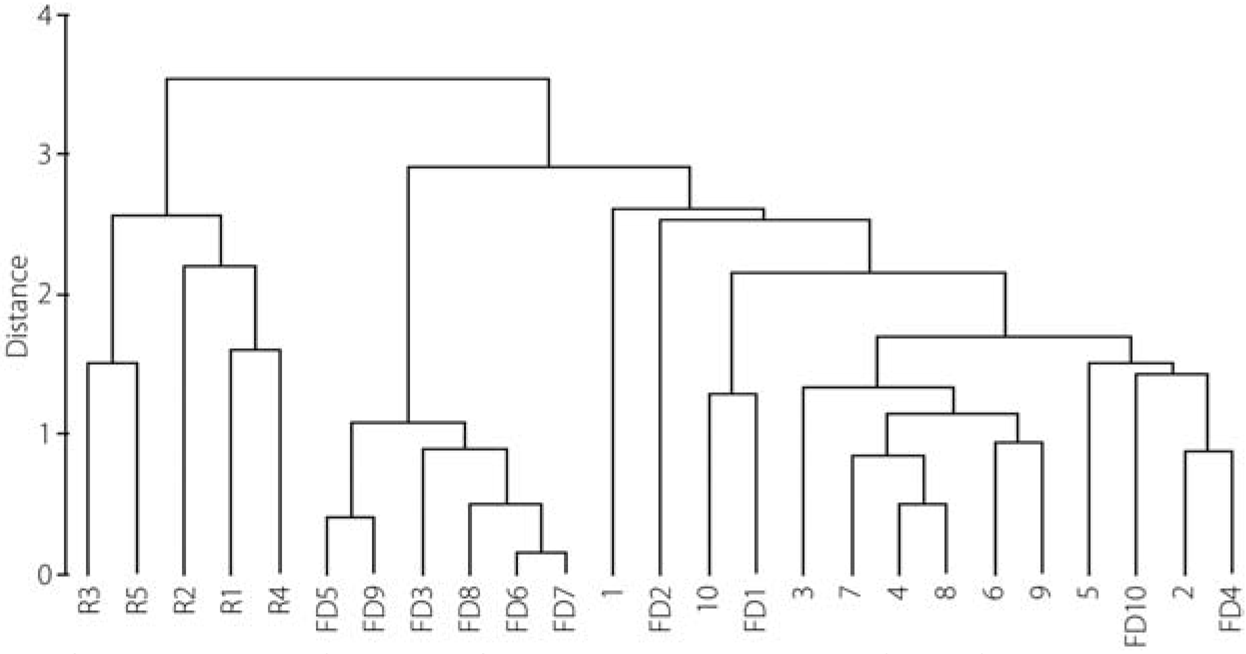

Figure 3. Dendrogram derived from the Bray-Curtis similarity measure showing classification of sites used in study based on habitat variables. Numbers = wetlands; R = river sites; FD = farm dams.

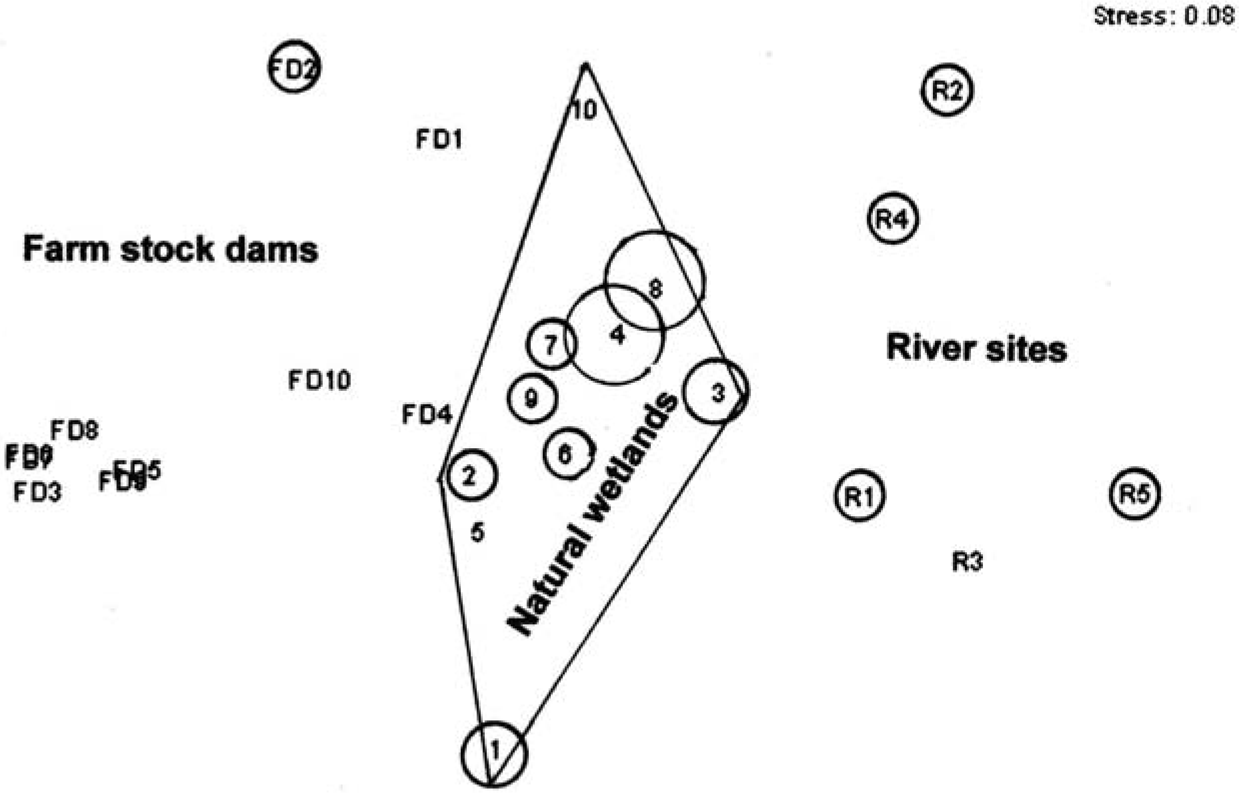

Figure 4. Two-dimensional (*nMDS*) ordination of sites used in the study. The circles drawn around the sites indicate relative abundance of adult and juvenile frogs (combined value) as follows: no circle = no *L. aurea* detected; smallest to largest circles = 1-10 individuals; 11-25 individuals; greater than 25 individuals. The solid line surrounds all wetlands sampled.

Discussion

This study confirms the presence of a highly-restricted population of the Green and Golden Bell Frog *Litoria aurea* in the Upper Molonglo River region of the Southern Tablelands near Hoskinstown, NSW. The species was found at thirteen sites - nine wetlands and at four locations on the Molonglo River. It occurs over a 13 km stretch of the Upper Molonglo River floodplain to the west of Hoskinstown, NSW and, based on the location of specific breeding sites, occupies an area of less than eight square kilometres. However, the area of occupation is likely to be larger than this because a further four kilometres of floodplain habitat that supports potentially suitable wetlands, was not surveyed due to a lack of property access. Some small wetlands that might be suitable can be seen on aerial photographs of this property. It is also possible that the species occurs along the Molonglo River downstream of the present study area although there appears to be little suitable wetland habitat in this steeper section of the river.

The population appears to be confined to the river and immediate floodplain, and the breeding sites that we found were all semi-natural ponds and lagoons associated with low-lying depressions and former stream channels, or were large pools in the Molonglo River. A feature of all occupied sites was that they were densely-vegetated with aquatic emergent vegetation and the banks also had a thick cover of grasses and sedges (Table 1). The multivariate analysis (Figs 3 and 4) revealed clear differences in habitat structure between natural wetlands, dams and sites surveyed along the river. The importance of aquatic vegetation cover at breeding sites occupied by *L. aurea* has been well documented (e.g. Humphries, 1979; Hamer *et al.* 2002; Pyke et al. 2002) although there is a lack of experimental demonstration of habitat preference.

The use of the river was unexpected because we thought that it would have provided unfavourable conditions since, within the study area, it is still highly-polluted with trace metals that kill fish and aquatic invertebrates (R. Norris, Freshwater Research Centre, University of Canberra, pers. comm.; see also Norris 1986). Nevertheless, slow-moving well-vegetated rivers once provided a component of the breeding sites occupied by the species in this region (Osborne *et al.* 1996; White and Pyke 1996). In the present study bell frogs were only detected along stretches of the river that had well-established thickets of emergent reeds (Table 1) and these kinds of habitat are also thought to provide cover from predators for both adults and tadpoles (Morgan & Buttemer 1996; van de Mortel & Goldingay 1998; Pyke and White 2000; 2001).

Surprisingly, the frogs do not appear to use the numerous farm dams that are dispersed through this area – the single occurrence was at a well-vegetated farm dam 30 m from a natural wetland (W1) that supported a large population of bell frogs. The extensive use of farm dams by frogs is well known (e.g. Hazel *et al.* 2001) and prior to the disappearance of *L. aurea* from the Southern Tablelands the species was frequently found calling and breeding in farm dams (Humphries 1979; Osborne *et al.* 1996; M.J. Littlejohn, University of Melbourne pers. comm.). The apparent avoidance of farm dams requires explanation. It may be that the particular farm dams in this region do not provide suitable habitat; most farm dams in this area typically lacked emergent vegetation cover (Table 3). Another possible reason for the avoidance of farm dams is that they may be unsuitable for long-term use by bell frogs because individuals that occupy them may be more likely to succumb to chytrid infection (see below).

The possible influence of mine waste pollution on chytrid infection

It is now widely accepted that the disease chytridiomycosis, caused by the chytrid fungal pathogen *Batrachochytrium dendrobatidis*, is responsible for serious declines of frogs in a number of countries, including Australia (Berger *et al.* 1998, 1999; Rachowicz *et al.* 2005; Schloegel *et al.* 2006). It may be the major reason for the broad-scale disappearance of populations of *L. aurea*, although this is difficult to determine retrospectively. The disappearance of all species of bell frog (*L. aurea, L. raniformis, L. castenea*) from the Southern Tablelands between 1979 and 1981 (Osborne *et al.* 1996) corresponds closely with the first detected occurrence of chytridiomycosis in frogs in eastern Australia (R. Speare, James Cook University, pers. comm.). Chytridiomycosis is clearly present in the Upper Molonglo River population. Several sick-looking specimens of the Green and Golden Bell Frog collected from the Upper Molonglo floodplain in 2001 were found to be infected by chytrid (detected during histological examination of the two frogs by DH and following the methods of Berger et al. 1998). Given the widespread decline of *L. aurea* in New South Wales, the survival of a small population of *L. aurea* that is also apparently infected with chytridiomycosis is particularly surprising.

We can only speculate as to the reason for the survival of this population. There is a possibility that polluted or saline wetlands, through their chemical characteristics (in particular any anti-fungicidal properties that are present) protect resident populations of frogs from chytrid infection. This possibility seems to be reasonable considering that many trace metals, such as copper, zinc, selenium, chromium, nickel, and lead, are known to be toxic to fungi (see Threlfall *et al.* this volume). It is possible that the prevalence or virulence of chytrid in the environment in this area is reduced by anti-fungicidal properties present in the river and in wetlands filled by flooding from the river. Further research is required to test this hypothesis.

It is worth commenting on the apparent avoidance of farm dams by the frogs since many of the farm dams that we surveyed were within dispersal distance of occupied wetlands. It may be that local selection has favoured frogs that avoid farm dams - since there may be an increased risk of being infected at these locations - or, as suggested by the habitat analysis, the farm dams may provide unsuitable habitat because of a lack of emergent vegetation cover and the frogs simply avoid these locations.

Livestock grazing and habitat protection

Agricultural grazing practices can affect wetlands in a number of ways that are likely to affect wildlife (Brock and Jarman 2000). The most important of these are the direct draining of wetlands and trampling and grazing by stock. Less obvious impacts include excessive surface movement of nutrients, weeds and agricultural chemicals into wetlands during heavy rainfall and localised flooding. Uncontrolled access to wetlands by livestock, or overstocking, may ultimately lead to their degradation. Since all populations of *L. aurea* found so far on the Upper Molonglo occur on properties used for livestock production consideration has to be given to the possible influence of these activities.

The areas supporting bell frogs in this region have been used for livestock grazing since the area was first settled by European farmers in the first half of the nineteenth century (Duffy 1969). Although large areas have remained uncultivated, pasture improvement – the conversion of native pastures to mixed exotic pastures – has been widespread. In recent years, the native tussock grassland at some locations with bell frog populations has been converted to improved pasture (Patmore 2001). The impact of these broad-scale changes is not known and will require continued monitoring.

Disturbance from livestock can vary considerably depending on seasonal conditions. Cattle show a preference for aquatic sedges and emergent rushes in wetland environments, a preference that leads to severe damage to the margin of these wetlands (Jansen and Robertson 2001). Intensive grazing and trampling by livestock can result in the trampling and removal of the reed beds and other ground level vegetation, thus exposing the frogs to increased predation. Excessive trampling can lead to soil compaction and pugging within the riparian zone, destabilising of banks by vegetation removal and trampling, and increases in soluble nutrients (Brock and Jarman 2000). Cattle also enter water bodies to graze; therefore both the margins of water bodies (where frogs frequently forage and shelter), and the calling sites and egg deposition sites within the water bodies, are likely to be disturbed (Appendix 1). In addition, when cattle walk through wetlands and defecate in them, there is an increase in turbidity and organic load.

Despite the very obvious effects that livestock can have on wetland vegetation, it is also quite likely that some form of livestock activity in wetlands may be required to prevent vegetation from completely choking up the water body (e.g. Marty 2005; Brock and Jarman 2000). Recent observations by Heard *et al.* (2006) on a related species *L. raniformis* in Victoria indicate that the long-term removal of livestock grazing may have a negative effect on the habitat conditions that suit this species. They argue that the occurrence of open microhabitats within the riparian zone (bare-soil, rocks and sparse vegetation on land; mats of submergent and floating vegetation in the water), when interspersed amongst more structurally complex microhabitats (important for other aspects of the ecology of the species), enhances habitat quality of wetlands for *L. raniformis*.

An adaptive approach requiring long-term monitoring of habitat conditions and frog populations is required in order to explore the possible relationships discussed above. It is quite possible that on some properties no change to current farm management is required - for example where it is obvious that current stocking levels and paddock management is not unduly damaging frog breeding sites or adjacent cover – however, at locations where frogs appear to be in decline active management may be required. Ideally such changes should be established with appropriate use of experimental controls and a consideration of independence in terms of selection of sites. For example, if some wetlands are to be excluded from livestock grazing, it is important that other similar wetlands continue to have livestock grazing, so that the ongoing effects of either of these treatments can be assessed.

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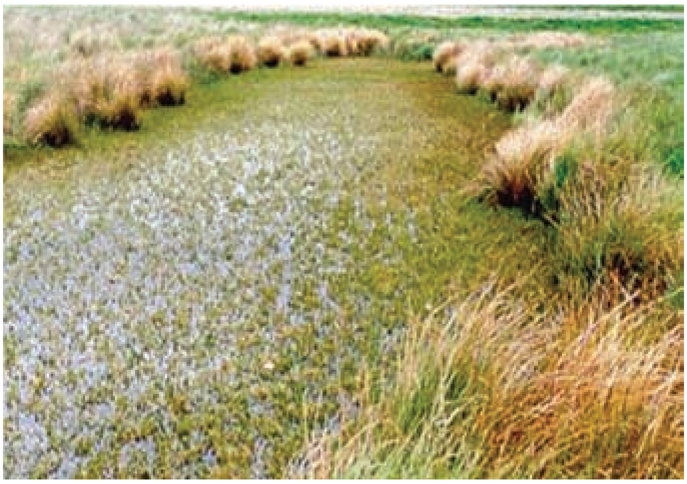
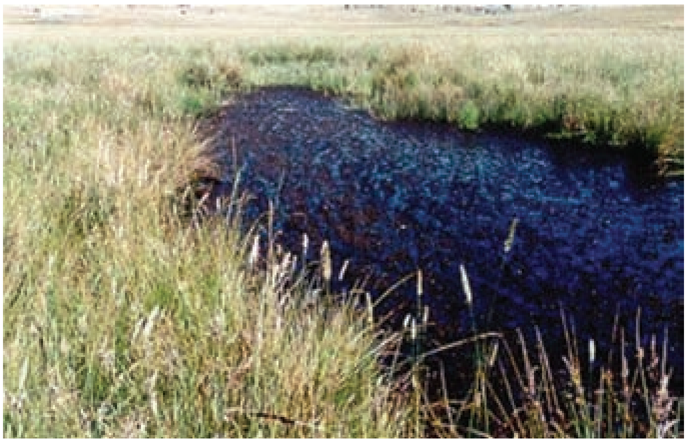
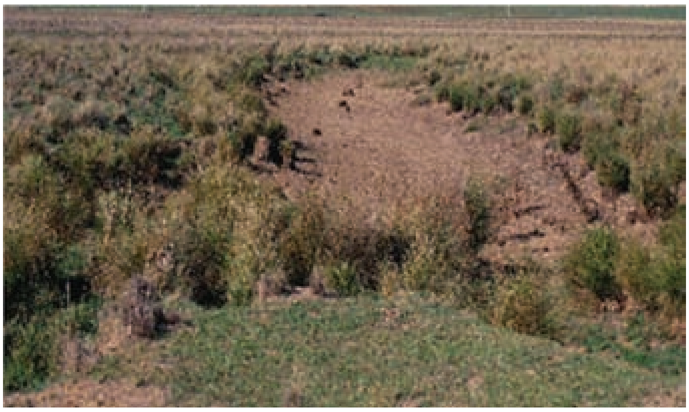
APPENDIX I



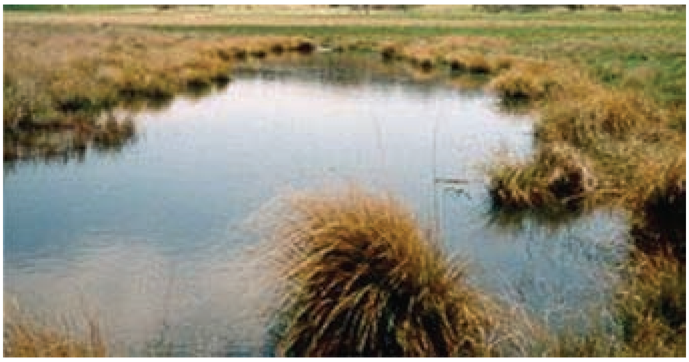
Wetland 1, October 2001. Counts at this time indicated that at least 23 adult/large juvenile Green and Golden Bell Frogs occupied the wetland and its margins.



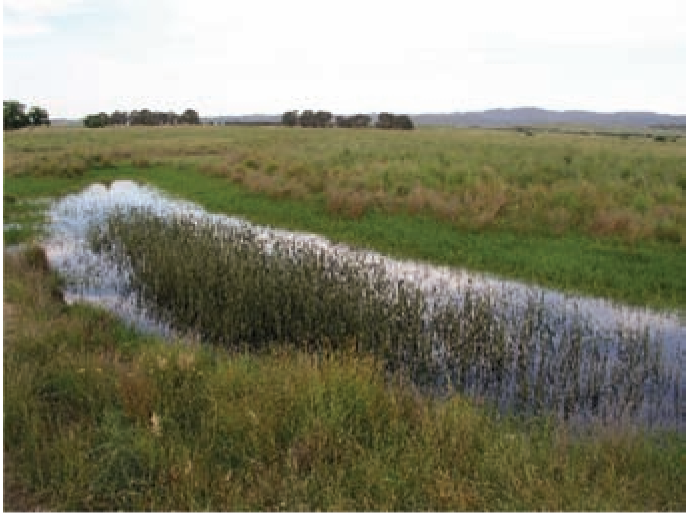
Wetland 1, December 2001 Emergent floating vegetation in the pond died following an outbreak by the haltica beetle that was feeding on pond millfoil. The bell frog population abandoned the wetland at this time.



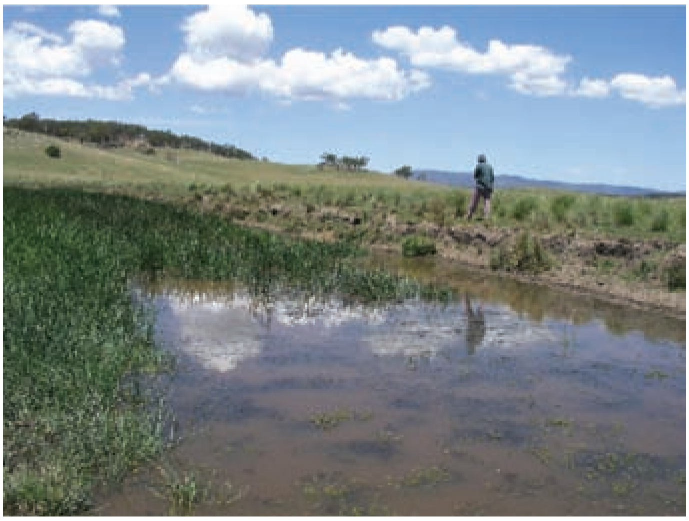
Wetland 1, Nov 2003. In the middle of prolonged drought.



Wetland 1, November 2005. Three bell frogs were recorded at this time providing a useful record of survival through three years of drought.



Former stream channel pool occupied by Green and Golden Bell Frogs on the upper Molonglo River. Note the matrix of tall tussock grassland dominated by *Poa labillardieri* that surrounds the wetland.



The effects of trampling by livestock was evident at some wetlands on the upper Molonglo River. Undercutting of banks well advanced This wetland has since been fenced by landholders to control access to the wetland by cattle (See next photograph).

APPENDIX I

The same wetland as in the previous photograph, 12 months after removal of livestock access. Long term monitoring will be required to determine whether such measures are suitable for continued use by frogs. It is likely that intermittent grazing by cattle will be required to maintain habitat suitable for Green and Golden Bell Frogs.

Some well-vegetated sections of the Molonglo River were occupied by Green and Golden Bell Frogs.

Typical in-stream habitat occupied by Green and Golden Bell Frogs within the bed of the Molonglo River.